Determination of Proton PDFs Using ATLAS Data

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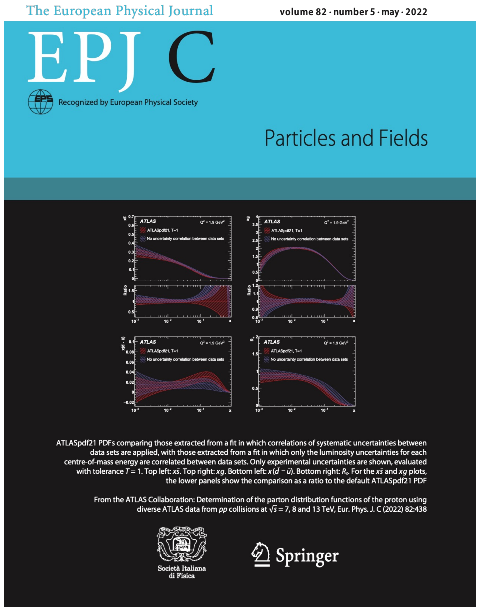


Unless stated otherwise, all the results (including tables+figures) are taken from [EPJC 82 (2022) 438]

Introduction

PDFs of the proton cannot be predicted from first principle

They are determined using relevant cross section measurements from collisions as ℓp, pp, …

They are universal (relying on the factorisation theorem), the determination from one process can be used as prediction for others

At hadron colliders, they are
- dominant uncertainty source for precision measurements
- becoming limiting factors for BSM searches

Important to improve our knowledge on PDFs by using relevant data at the LHC

Inputs and ATLAS PDF Fits (ATLASpdf21)

ATLAS has performed a number of PDFs fits using its data since a decade

This talk will focus on describing briefly the latest analysis (EPJC 82 (2022) 438) using a large number of measurements from different processes:

Data set	$\sqrt{s}$ [TeV]	Luminosity [fb^{-1}]	Decay channel	Observables entering the fit
Inclusive $W, Z/\gamma^*$	7	4.6	e, μ combined	η_ℓ (W), y_Z (Z)
Inclusive Z/γ^*	8	20.2	e, μ combined	$\cos\theta^*$ in bins of $y_{\ell\ell}, m_{\ell\ell}$
Inclusive W	8	20.2	μ	η_μ
$W^\pm$ + jets	8	20.2	e	p_{T}^W
Z + jets	8	20.2	e	$p_{\mathrm{T}}^{\mathrm{jet}}$ in bins of $\lvert y^{\mathrm{jet}}\rvert$
$t\bar{t}$	8	20.2	lepton + jets, dilepton	$m_{t\bar{t}}$, p_{T}^t, $y_{t\bar{t}}$
$t\bar{t}$	13	36	lepton + jets	$m_{t\bar{t}}$, p_{T}^t, y_t, $y_{t\bar{t}}^{\mathrm{b}}$
Inclusive isolated γ	8, 13	20.2, 3.2	-	E_{T}^γ in bins of η^γ
Inclusive jets	7, 8, 13	4.5, 20.2, 3.2	-	$p_{\mathrm{T}}^{\mathrm{jet}}$ in bins of $\lvert y^{\mathrm{jet}}\rvert$

together with Deep Inelastic Scattering (DIS) data from ep collisions at HERA

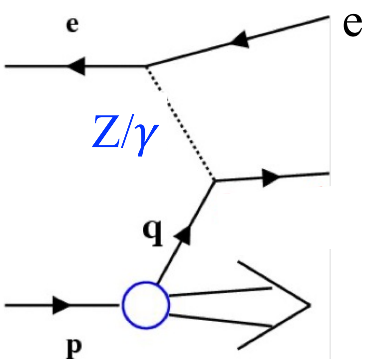
The fits were performed using xFitter

Why HERA Electron/Positron-Proton DIS Input?

HERA provides two dominant neutral/charged current (NC/CC) DIS processes

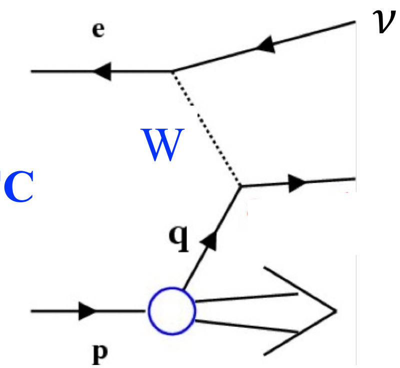
NC/CC cross section data have been the primary inputs for constraining the PDFs of the proton

NC



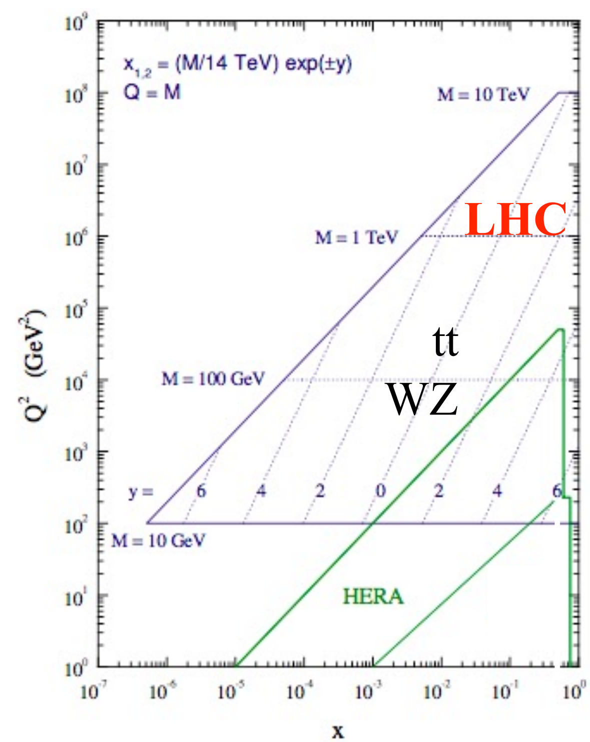
$$\sigma_{\rm NC} \sim F_2 + F_3$$
$$F_2 \sim x\,(q+\bar{q})$$
$$F_3 \sim x\,(q-\bar{q})$$

CC



$$\sigma_{\rm CC} \sim W_2 + W_3$$
$$W_2 \sim xU + x\bar{D}$$
$$W_3 \sim xU - x\bar{D}$$
$$U = u + c$$
$$\bar{D} = \bar{d} + \bar{s}$$

Q^2: four moment transfer squared, Bjorken x: proton's momentum fraction carried by struck parton

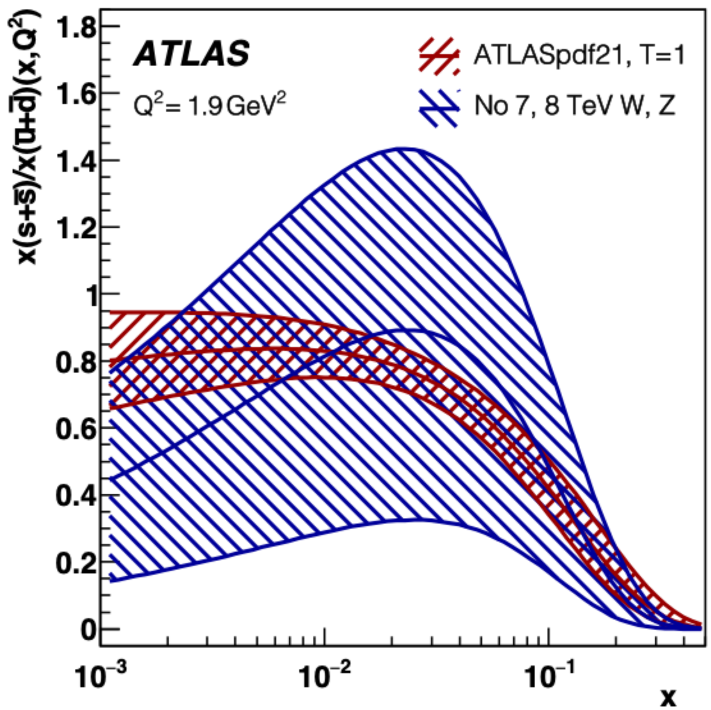


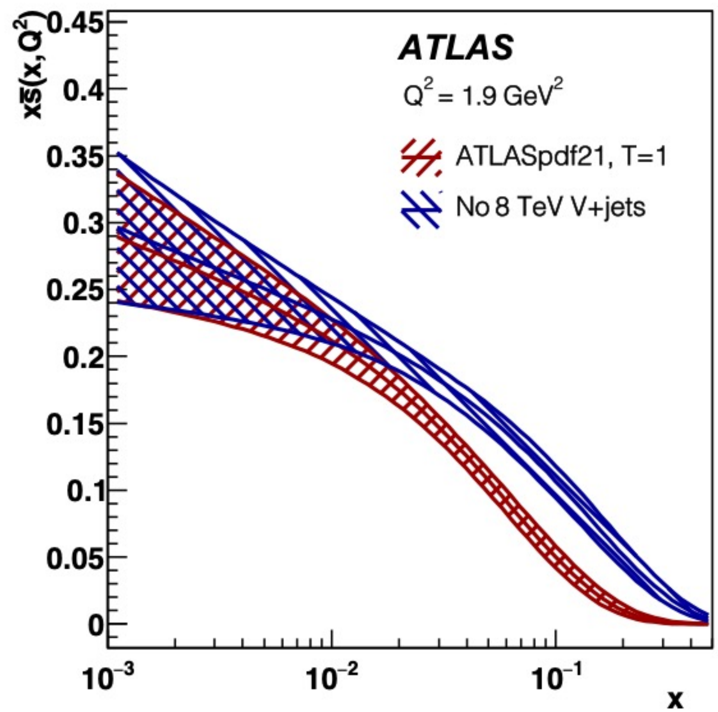
→ However HERA NC/CC data alone do not allow to distinguish sea quarks d and s
Also, the data precision at high x (and high Q^2) are statistically limited

Main Features of the Analysis

- ➢ Use diverse ATLAS measurements to asses its impact on PDFs (a la global PDFs)
- ➢ The main correlations within one dataset and between different measurements are known and taken into account in the analysis
- ➢ Theoretical predictions are known to NNLO for QCD and NLO for EW
- ➢ The scale uncertainties (for missing higher order contribution) were studied and were found comparable with the other uncertainties for the inclusive W and Z/γ^* data

Impact of Different Data Sets (Two Examples)





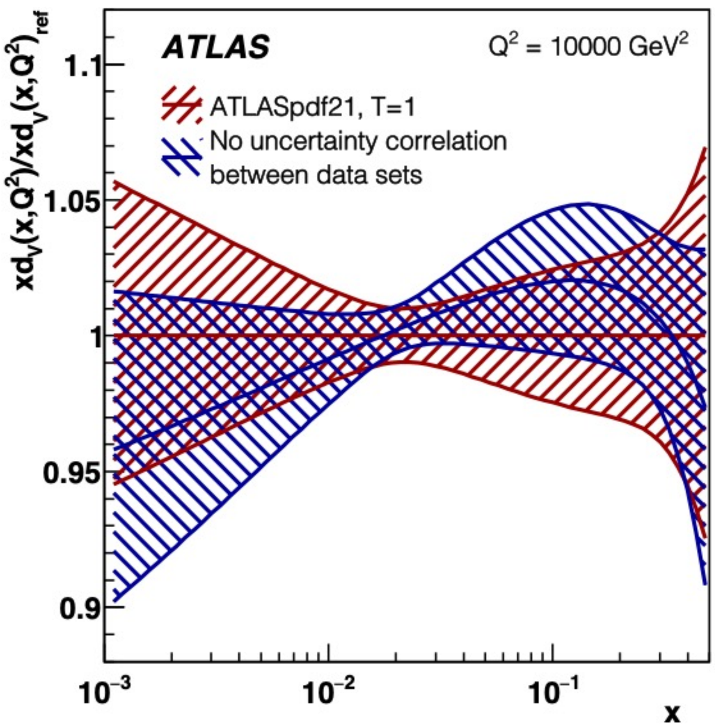
The strange fraction can not be reliably determined without 7 TeV W, Z data.

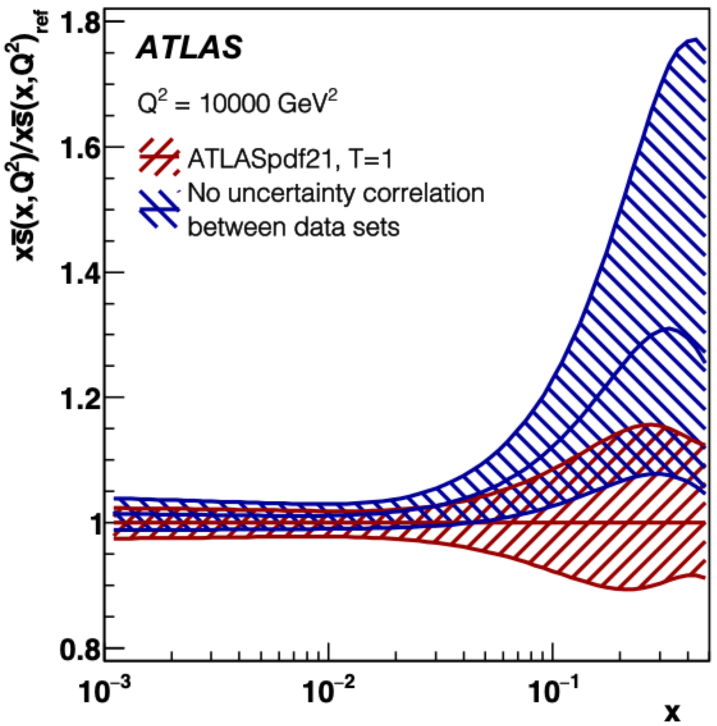
The data also improve the precision of other PDFs.

The data sets are now used by all other global PDF groups

The 8 TeV V+jets data helps to remove previous ambiguity (double minima) in the strange sea quark shape at high x

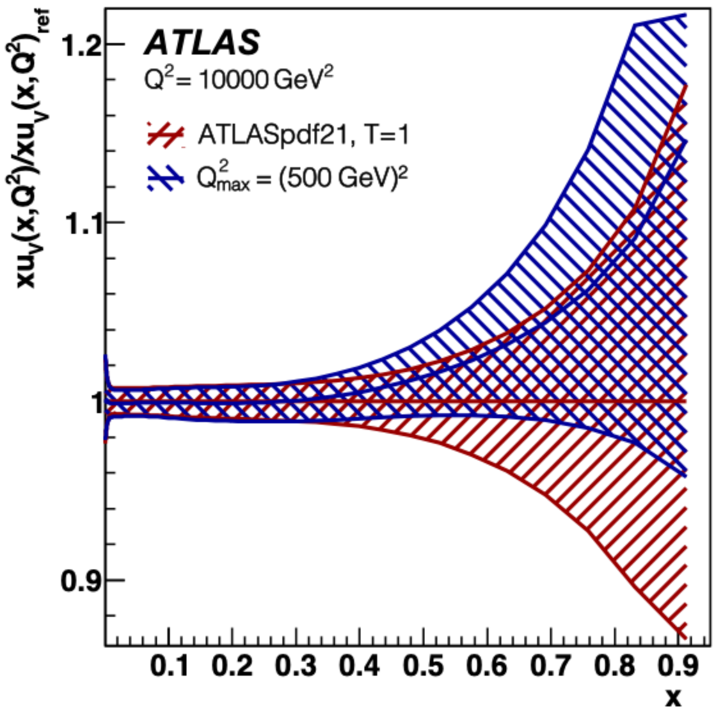
Impact of the Correlation Between Data Sets

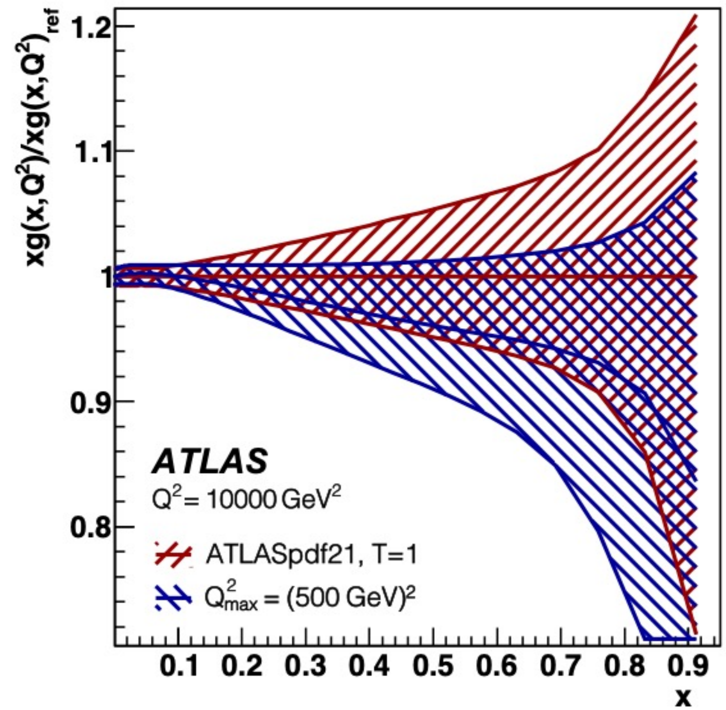




When the correlations of the systematic uncertainties between V+jets, ttbar, inclusive jets are not applied, substantial difference wrt the nominal PDFs is observed at 10,000 GeV^2, a scale relevant for precision LHC physics

PDFs at high Q^2 vs New Physics



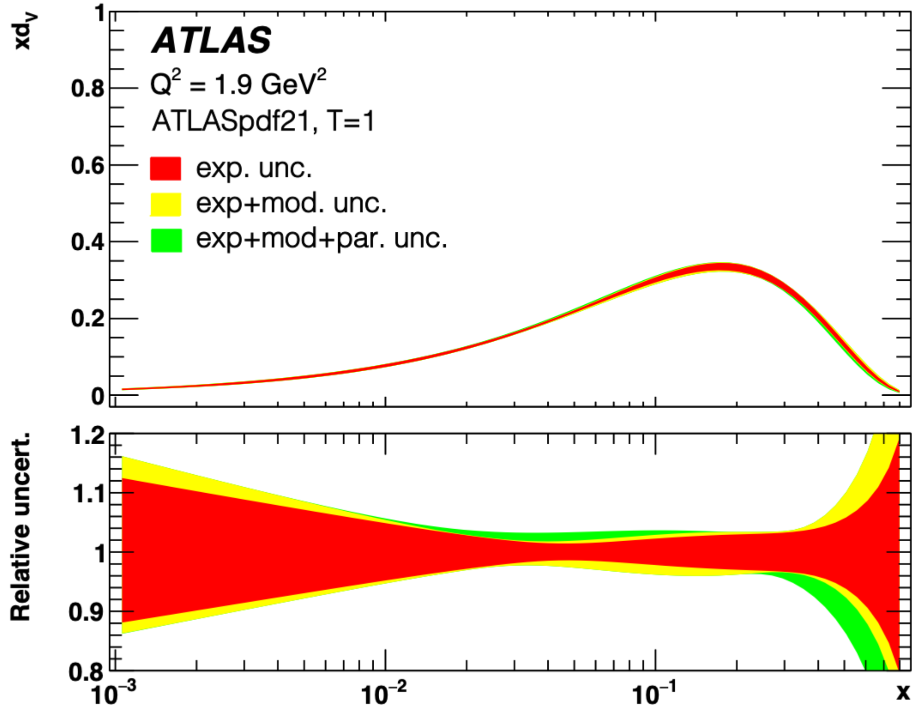


Subtle effects of BSM physics may be present in high-scale data. Therefore the PDFs may absorb these BSM physics effects

To check this, a fit without data beyond $(500\ \mathrm{GeV})^2$ was performed, the difference of the resulting PDFs wrt the nominal ones remains within the experimental uncertainty

Adding Model and Parameterisation Uncertainties

Central χ^2/NDF	2010/1620
Model variations	
$Q^2_{\min} = 12.5\ \text{GeV}^2$	1947/1571
$Q^2_{\min} = 7.5\ \text{GeV}^2$	2076/1660
$m_c = 1.45$ GeV (sym)	2025/1620
$Q^2_0 = 1.6\ \text{GeV}^2$ (sym)	2018/1620
$m_b = 4.3$ GeV	2016/1620
$m_b = 4.1$ GeV	2014/1620
$m_t = 175.0$ GeV	2063/1620
$m_t = 172.5$ GeV	2018/1620
$R = 0.4$	2080/1620
Parameter variations	
$F_{u_v}, D_{\bar{d}}$	2007/1620



In general, model & parameterisation uncertainties are small except for e.g. *xd*

PDF parameterisation:

$$xg(x) = A_g x^{B_g} (1-x)^{C_g} P_g(x) - A'_g x^{B'_g} (1-x)^{C'_g}$$

$$xq_i(x) = A_i x^{B_i} (1-x)^{C_i} P_i(x)$$

with $P_i(x) = 1 + D_i x + E_i x^2$

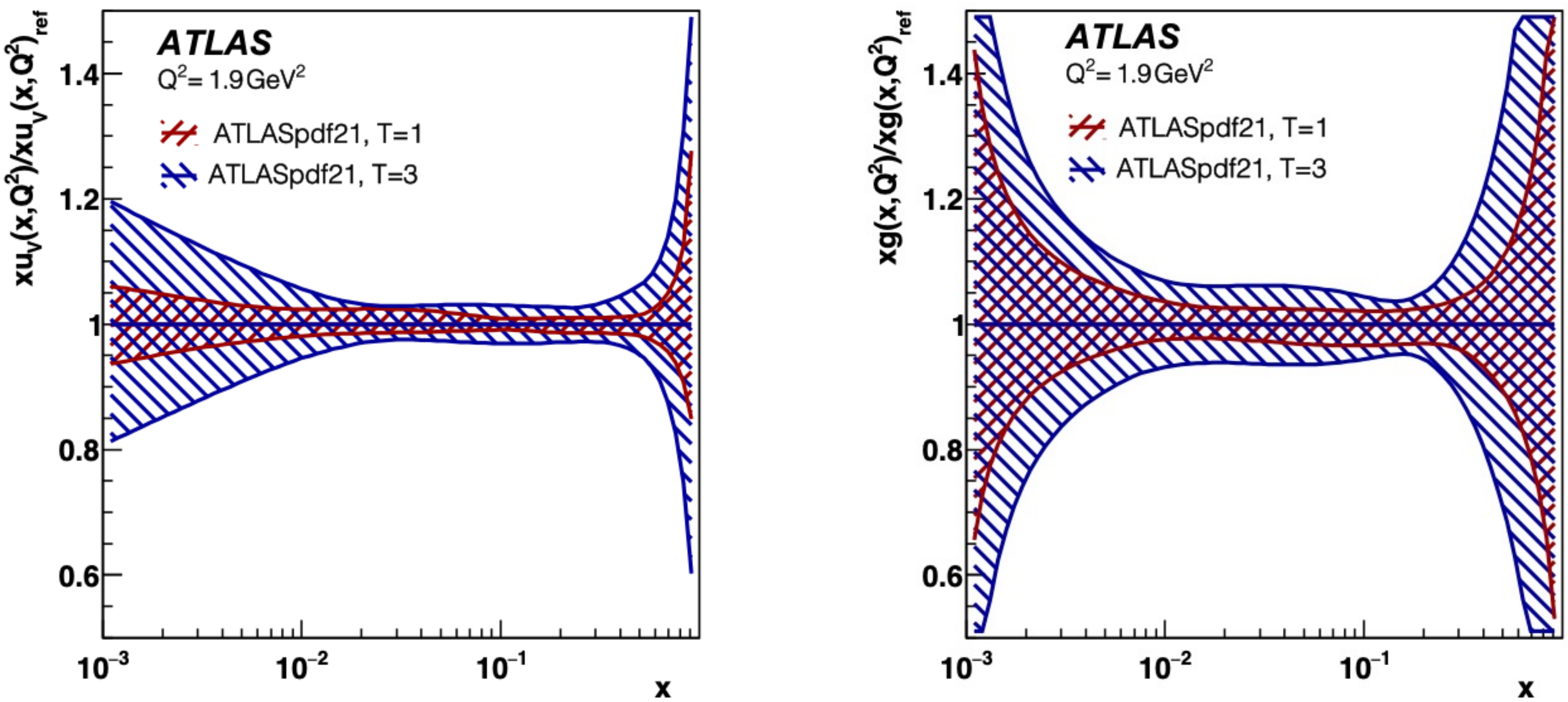
PDF constraints:

No more constraints $A_{\bar{u}} = A_{\bar{d}}, \quad B_{\bar{u}} = B_{\bar{d}}$

A_g is fixed by momentum sum rule, and A for u and d valence PDFs are fixed by quark number sum rules.

$C'_g = 25 \gg C_g$ suppresses negative contribution at high x

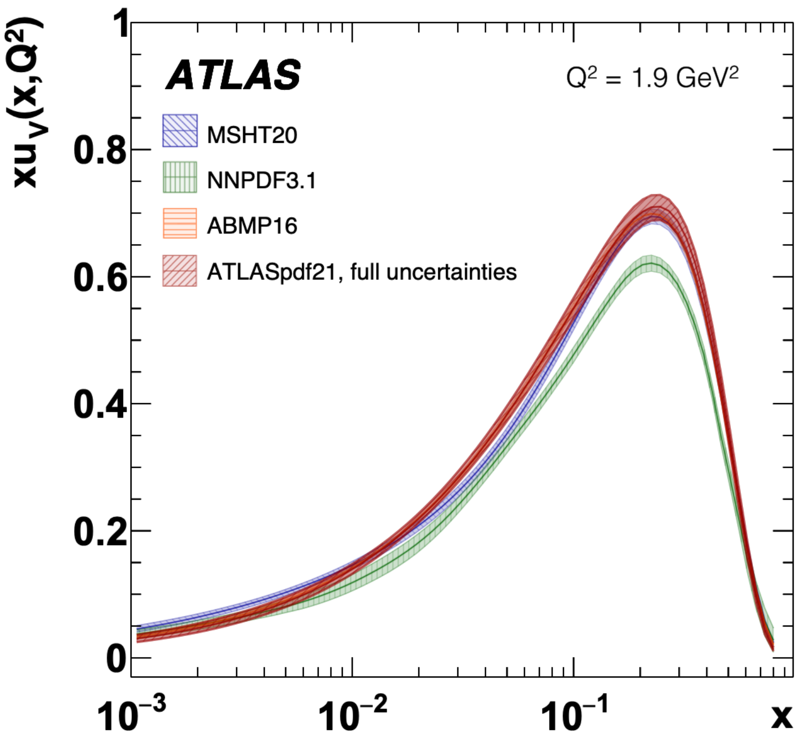
Tolerance 1 vs 3

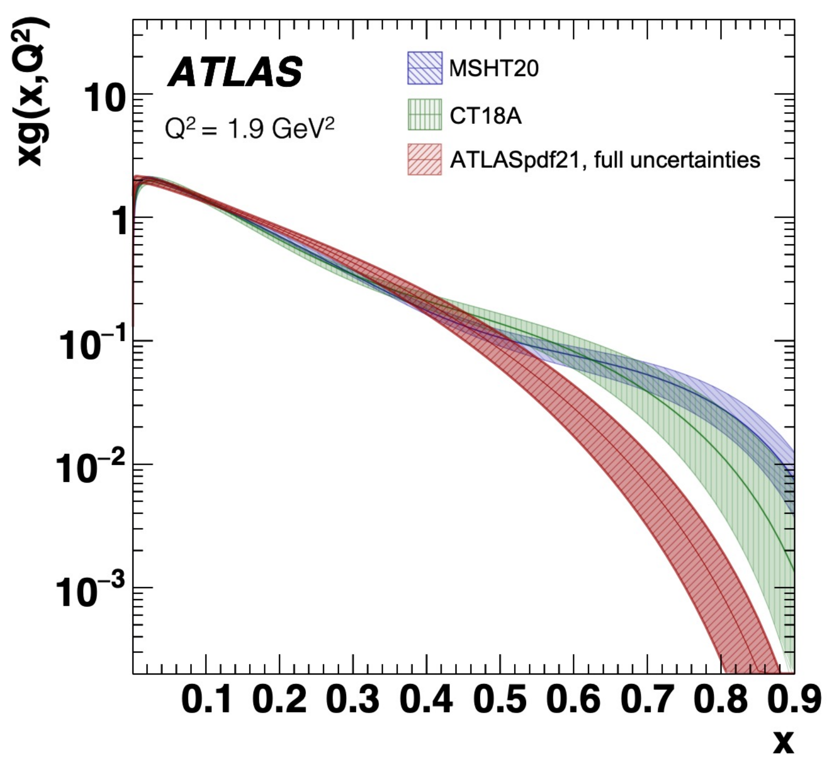


The default $\Delta\chi^2 = T = 1$ gives aggressive PDFs uncertainty. However the global χ^2 /NDF=2010/1620 indicates a different choice is needed.

This was studied finding tolerance values in the range 2.4-4.2 for different data sets. A simple choice of T=3 was made for the final ATLASpdf21 set.

Comparison ATLASpdf21 with Other PDF Sets





ATLASpdf21 PDFs are in good agreement with other global PDF sets, with a few exceptions, e.g. NNPDF3.1 for *xu* valence PDF, and *xg* PDF at very high *x*

Summary

Differential cross sections of inclusive W/Z, W/Z+jets production and top-quark pairs measured by ATLAS at different energies are used to constrain the PDFs

The impacts of different data sets and of the correlation of systematic uncertainties are studied in detail

ATLASpdf21 provides comparable precision with that from the other PDF sets

Much efforts still needed if we aim for PDF uncertainties of $\mathcal{O}(\sim 1\%)$